ERNEST ORLANDO LAWRENCE
BERKELEY NATIONAL LABORATORY

Estimate of Technical Potential for Minimum Efficiency Performance Standards in 13 Major World Economies

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July 2012

This work was supported by the Collaborative Labeling and Appliance Standards Program through the U.S. Department of Energy under Contract No. DE-AC02-05CH11231.

Disclaimer

Acknowledgements

We would like to thank our colleagues from the International Energy Studies group at LBNL for their collaboration in the elaboration of this BUENAS scenario. Specifically, we want to thank Nihar Shah, Won Park, Nakul Sathaye and Amol Phadke for sharing their work with us. Special thanks go for Won Park and Nan Wishner for their careful review of the report. We also acknowledge our sponsor and project managers at CLASP for their continuous support.

Acronyms and Abbreviations

AFUE	annual fuel utilization efficiency
AUS	Australia
BAT	best available technology
BAU	business as usual
BRA	Brazil
BUENAS	Bottom-Up Energy Analysis System
CAN	Canada
CFL	compact fluorescent lamp
CHN	China
CLASP	Collaborative Labeling Appliances and Standards Program
CO_2	carbon dioxide
EC	European Commission
EF	Energy Factor
EU	European Union
EEI	energy-efficiency index
EER	energy-efficiency ratio
GJ	gigajoule
Gt	gigaton
HP	heat pump
IDN	Indonesia
IND	India
JAP	Japan
kg	kilogram
KOR	Korea
kVA	kilovolt ampere
kW	kilowatt
kWh	kilowatt hour
LBNL	Lawrence Berkeley National Laboratory
LEAP	Long range Energy Alternatives Planning System
LCD	liquid crystal display
LED	light-emitting diode
lm/W	lumens per watt
MEX	Mexico
MEPS	minimum efficiency performance standard
Mt	million tons (of CO_2)
NES	national energy savings
NIA	national impacts analysis
OLED	organic LED
Ppm	parts per million
PJ	petajoule
RUS	Russia
SEAD	super-efficient equipment and appliance deployment
SEER	seasonal energy-efficiency ratio
TSD	technical support document

TV	television
UEC	unit energy consumption
USA	United States of America
TWh	terawatt hour
U.S. DOE	United States Department of Energy
VIP	vacuum insulated panels
W	watts
ZAF	South Africa

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Executive Summary

As part of the ongoing effort to estimate the foreseeable impacts of aggressive minimum efficiency performance standards (MEPS) programs in the world's major economies, Lawrence Berkeley National Laboratory (LBNL) has developed a scenario to analyze the technical potential of MEPS in 13 major economies around the world[1]. The "best available technology" (BAT) scenario seeks to determine the maximum potential savings that would result from diffusion of the most efficient available technologies in these major economies.

The analysis of the BAT scenario uses the Bottom-Up Energy Analysis System (BUENAS) to estimate potential impacts and savings for a wide range of residential and industrial end uses. BUENAS has previously been used to estimate potential national energy savings (NES) and carbon dioxide (CO_2) mitigation potential from MEPS around the world, for the Collaborative Labeling and Appliance Standards Program (CLASP) and the Super-efficient Equipment and Appliance Deployment (SEAD) initiative (McNeil et al. 2011).

In this analysis, we bring together engineering knowledge of the technologies evaluated, from studies such as *Max Tech and Beyond* (Desroches and Garbesi 2011), with BUENAS' capability to model the international impact of MEPS. This combination allows us to provide highly accurate estimates of maximum potential savings resulting from implementation of standards requiring BAT in 13 major economies around the world. We assume that the BAT standard would become mandatory worldwide as of 2015. BAT is defined as the most efficient product on the market for each end use, or the most efficient product that could be engineered with currently available components.

We present the impacts of BAT MEPS for each end use in terms of site energy savings and CO_2 emissions savings in 2020 and in 2030. We find that the impacts of adopting BAT MEPS globally are:

- 1,200 terawatt hours (TWh) of electricity savings in 2020 and 2,300 TWh in 2030
- 1,400 petajoules (PJ) of fuel savings in 2020, and 3,500 PJ in 2030
- 27-percent energy reduction among residential end uses and 6-percent among industrial end uses in 2030
- 860 million tons (Mt) reduction in annual CO_2 emissions by 2020 and 1,700 Mt by 2030
- Emissions reductions equal to 11 percent of total reduction needed to reach 450 parts per million (ppm) CO_2 by 2030
- 17 gigatons (Gt) of cumulative emissions savings between 2015 and 2030
- Emissions reductions from electricity generation equal to 60 percent of the total reduction needed to reach 450 ppm CO_2 by 2030

Scenario Description and Rationale

The BAT scenario targets represent the maximum achievable energy-efficient designs, based on emerging technologies that are commercialized (or will be soon) but have a small market share, or designs that combine the most efficient currently available components. In cases where neither of these options is available, the analysis uses an aggressive target from an existing efficiency program. BAT targets exclude promising technologies that are in development but are several years away from commercialization. In

[1] The countries modeled in BUENAS are the SEAD participating countries: Australia, Brazil, Canada, the European Union, India, Indonesia, Japan, Mexico, Russia, South Korea, South Africa, and the United States. China, an observer to the SEAD process, is modeled as well. Overall they represent 77% of world energy consumption in 2005 (IEA data).

addition, large-scale production of products or technologies that meet the BAT targets must be feasible by 2015.

The BAT scenario is built on the BUENAS business-as-usual (BAU) scenario. BAT targets are determined according to the above criteria using a variety of sources, such as: technical analysis studies performed by LBNL in support of the SEAD initiative, the *Max Tech and Beyond* study, technical support documents (TSDs) developed for United States Department of Energy (U.S. DOE) standards programs, preparatory studies from the European Commission Ecodesign program, and the Japanese Top Runner program's target definitions.

<u>Scope of Scenario Coverage</u>

Because BUENAS has been used to support the activities of SEAD (which is an initiative within the Clean Energy Ministerial process), BUENAS includes all SEAD participating countries as well as China. Table ES-1 shows the appliances and countries covered in the BAT and BAU scenarios in the current study. The end uses and countries covered in the BAU scenario are shaded, and the BAT is marked by an "X." Data on BAT for commercial sector end uses were not sufficient to include in this study. In the residential and industrial sectors, the BAT scenario coverage is broad, including nearly all end uses. Notable exceptions are cooking and space heating, for which coverage is also sparse in the current version of BUENAS.

Table ES-1. Comparison of BAU and BAT Scenario Scope

Shaded cells = countries covered in BAU scenario; X = countries covered in BAT scenario

	Appliance	AUS	BRA	CAN	CHN	EU	IND	IDN	JPN	KOR	MEX	RUS	USA	ZAF
RES	Air Conditioner	X	X	X	X	X	X	X	X	X	X	X	X	X
	Central AC	X		X							X		X	
	Cooking Equip.													
	Fans	X	X	X	X	X	X	X	X	X	X	X	X	X
	Laundry				X	X				X	X			
	Lighting	X	X	X	X	X	X	X	X	X	X	X	X	X
	Freezers					X							X	
	Refrigerators	X	X	X	X	X	X	X	X	X	X	X	X	X
	Boilers			X	X	X							X	
	Furnaces			X									X	
	Space Heating													
	Standby Power	X	X	X	X	X	X	X	X	X	X	X	X	X
	Televisions	X	X	X	X	X	X	X	X	X	X	X	X	X
	Water Heaters	X		X	X	X					X		X	
IND	Distribution Transformers			X	X		X						X	
	Electric Motors	X	X	X	X	X	X	X	X	X	X	X	X	X

AC = air conditioning; AUS = Australia; BRA = Brazil; CAN = Canada; CHIN = China; EU = European Union; IND = India; IDN = Indonesia; JPN = Japan; KOR = South Korea; MEX = Mexico; RUS = Russia; USA = United States of America; ZAF= South Africa

Potential Savings Results and Conclusions

Table ES-2 presents the estimated end-use energy savings and CO_2 emissions reductions in 2020 and 2030 for the BAT scenario.

Table ES-2. Final Energy Savings and Emissions Reductions from BAT Scenario

	Annual Savings in 2020				**Annual Savings in 2030**				**Cumu-lative**
	Elec.	Gas	% reduction vs. BAU	CO_2	Elec.	Gas	% reduction vs. BAU	CO_2	CO_2
End Use	TWh	PJ	%	Mt	TWh	PJ	%	Mt	Gt
Air Conditioning	220		20%	150	550		37%	360	3.3
Fans	65		32%	54	130		54%	100	1.1
Lighting	200		42%	120	100		22%	60	1.7
Refrigerators & Freezers	130		21%	88	320		44%	200	1.9
Space Heating	0	690	6%	59	0	1,800	14%	150	1.3
Standby	150		65%	94	270		90%	170	1.8
Television	51		28%	30	100		45%	58	0.6
Laundry	40		15%	24	90		28%	65	0.7
Water Heating	140	740	18%	120	320	1,700	37%	250	2.4
Total Residential	**1,000**	**1,400**	**16%**	**740**	**1,900**	**3,500**	**27%**	**1,400**	**14.8**
Transformers	44		11%	31	130		27%	84	0.7
Motors	130		2%	90	310		5%	210	1.9
Total Industry	**170**		**3%**	**120**	**440**		**6%**	**290**	**2.6**
Total	**1,200**	**1,400**	**10%**	**860**	**2,300**	**3,500**	**19%**	**1,700**	**17.4**

Our study shows that implementation of aggressive policies targeting technically achievable efficiencies can reduce final energy consumption by 19 percent in 2030 in the residential and industrial sectors compared to business as usual. As a result, worldwide annual CO_2 emissions would be reduced by 860 Mt in 2020 and 1.7 Gt in 2030. As a comparison, recently implemented or in-progress standards from SEAD partner countries will save an estimated 220 Mt of CO_2 by 2030 (McNeil et al., 2012). To put our results in context, we compare them to the reductions that the International Energy Agency (IEA) deems necessary to stabilize global CO_2 concentration at 450 ppm (IEA 2010). Emissions mitigation from the BAT scenario would cover about 11 percent of the total emissions gap of 15 Gt[2], which includes energy demand reductions in buildings, industry, and transport as well as increases in the share of renewable energy. The BAT scenario provides 80 percent of required savings target for residential buildings and 25 percent of the savings for industry. Overall, implementation of BAT for electricity end uses in the residential and industrial sectors would provide 60 percent of the total final electricity demand reduction that is needed.

The main message of the BAT scenario is that widespread adoption of technologies that will already be marketable in the buildings and industry sector by 2015 could have a much greater impact on energy use and CO_2 emissions than current policies would have.

[2] IEA's *World Energy Outlook 2010*. Comparison of "current policies" and "450 ppm" scenarios in 2030.

1. Introduction

As part of the ongoing effort to estimate the foreseeable impacts of aggressive minimum efficiency performance standards (MEPS) programs in the world's major economies, Lawrence Berkeley National Laboratory (LBNL) has developed a scenario to analyze the technical potential of MEPS in 13 major economies around the world. The "best available technology" (BAT) scenario seeks to determine the maximum potential savings that would result from diffusion of the most efficient available technologies in major economies around the world.

Our analysis uses the Bottom-Up Energy Analysis System (BUENAS) (McNeil et al. 2011) to estimate potential impacts and savings of the BAT MEPS scenario on a wide range of end uses in the residential and industrial sectors. BUENAS is designed to provide policy makers with estimates of potential impacts of MEPS for a variety of products at the international and/or regional level. Because BUENAS has been used to support the activities of the Super-efficient Equipment and Appliance Deployment (SEAD) project, an initiative within the Clean Energy Ministerial process, the countries included in BUENAS are SEAD participating countries, as well as China, an observer to SEAD. These countries together accounted for 77 percent of total global energy consumption in 2005 (McNeil et al. 2011).

Few studies aside from the ones developed in the BUENAS framework (McNeil et al., 2012, McNeil et al., 2008), have rigorously and systematically assessed the global energy and emissions reduction potential that is technically achievable through standards. In this analysis, we bring together engineering knowledge of the technologies evaluated in studies such as *Max Tech and Beyond* (Desroches and Garbesi 2011) and BUENAS' international modeling capability, to provide the most accurate available estimates of maximum potential worldwide savings from standards.

To estimate the full potential of existing efficient technologies, we assume that MEPS implemented in 2015 would make these technologies mandatory worldwide. BAT is considered to be the most efficient product on the market for each end use or a highly efficient product that could be engineered with currently available components. This definition of BAT does not include promising technologies that are still in development and several years away from commercialization. In addition, this definition of BAT requires that large-scale production be feasible by 2015.

The remainder of this report describes the scope of our study and the details of the BAT scenario. For each end use, we explain the assumptions and the BUENAS calculation methodology used. We then describe the impacts of the BAT standards for each country and for each end use in terms of site (final) energy savings, and carbon dioxide (CO_2) emissions savings in 2020 and in 2030 as well as 2015-2030 cumulative CO_2 emissions savings.

2. Scope of Study

The countries covered in BUENAS and their International Standards Organization acronyms are:

- Australia (AUS)
- Brazil (BRA)
- Canada (CAN)
- China (CHN)
- European Union (EU)
- India (IND)
- Indonesia (IDN)
- Japan (JAP)
- Mexico (MEX)
- Russia (RUS)
- South Korea (KOR)
- United States (USA)
- South Africa (ZAF)

The BAT scenario is a subset of the business-as-usual (BAU) scenario in BUENAS. Table 1 shows the countries and end uses covered under the BAT and BAU scenarios in this study. The end uses and countries covered in the BAU scenario are shaded, and the BAT is marked by an "X." Data on best available technologies for commercial sector end uses were not sufficient to include in this study. In the residential and industrial sectors, BAT scenario covers nearly all end uses. Notable exceptions are cooking and space heating, for which coverage is also sparse in the current version of BUENAS.

Table 1. Comparison of BAU and BAT Scenario Coverage

Shaded cells = countries covered in BAU scenario; X = countries covered in BAT scenario

	Appliance	AUS	BRA	CAN	CHN	EU	IND	IDN	JPN	KOR	MEX	RUS	USA	ZAF
RES	Air conditioner	X	X	X	X	X	X	X	X	X	X	X	X	X
	Central air cond.	X		X							X		X	
	Cooking Equip.													
	Fans	X	X	X	X	X	X	X	X	X	X	X	X	X
	Laundry				X	X				X			X	
	Lighting	X	X	X	X	X	X	X	X	X	X	X	X	X
	Freezers					X							X	
	Refrigerators	X	X	X	X	X	X	X	X	X	X	X	X	X
	Boilers			X	X	X							X	
	Furnaces			X									X	
	Space heating													
	Standby power	X	X	X	X	X	X	X	X	X	X	X	X	X
	Televisions	X	X	X	X	X	X	X	X	X	X	X	X	X
	Water heaters	X		X	X	X					X		X	
IND	Distribution transformers			X	X	X	X						X	
	Electric motors	X	X	X	X	X	X	X	X	X	X	X	X	X

3. Scenario Description

The BAT scenario identifies efficiency targets representing the maximum achievable energy-efficient designs, based on efficient emerging technologies or an engineering analysis that assumes a design incorporating a combination of the most efficient available components.

An example of a design that achieves high energy efficiency by combining the most efficient currently available components would be an energy-efficient refrigerator that combines vacuum insulating panels (VIPs), a linear variable-speed compressor, and adaptive defrost, among other components. Each of these components is currently available on the market, but no single refrigerator is sold with all of them.

Alternatively, the BAT target is based on emerging technologies that are commercialized (or will be shortly) but command a small market share. An example of such an emerging technology is light-emitting diode (LED) lighting.

In cases where neither of the above options is available, BAT uses an aggressive target from an existing efficiency program (such as A+++ refrigerators in the EU). BAT targets exclude promising technologies that are still in development but are several years away from commercialization. In addition, for this scenario, large-scale production of products that meet BAT targets must be feasible by 2015.

The BAT scenario is built on the BUENAS business-as-usual (BAU) scenario. BAT targets are determined according to the above criteria using a variety of sources, such as: LBNL technical analysis studies in support of the SEAD initiative, the *Max Tech and Beyond* study, technical support documents (TSDs) developed for the United States Department of Energy (U.S. DOE) standards programs, preparatory studies from the European Commission (EC) Ecodesign program, and the Japanese Top Runner program’s target definitions.

In contrast to scenarios previously developed in BUENAS (McNeil et al., 2012), in which country or regional considerations are taken into account in determining MEPS targets, in the BAT scenario we identify one common international BAT target for each end use. This target is generally characterized with an efficiency rating that we use to adjust the unit energy consumption (UEC) in the BAU scenario, to determine the UEC of the BAT scenario for each country. The BAT targets are therefore adjusted for typical appliance capacities and usage profiles specific to each country. For example, the lighting UECs are adjusted for typical wattage of incandescent bulbs and hours of usage in each country. As a consequence, different countries have different UEC targets for the same technology with the same efficiency.

For the BAU, we rely on McNeil et al. (2011) and in Zhou et al. (2010) for China. Our base case takes into account shifts between different technologies or product classes. For example the progressive phase out of traditional cathode ray tubes televisions to LCD and plasma screen. The BAU also assumes a gradual improvement in efficiency for most end uses for the United States and the European Union where other market mechanisms such as ENERGY STAR and the European labeling program have been proven to move the market towards more efficient products. For other countries where labeling programs are either inexistent or more recently implemented (our base year being 2010), a frozen efficiency base case is assumed. An exception to this is lighting, for which we assume that incandescent bulbs gradually get replaced by CFLs until all bulbs are CFLs by 2020 in the United States and 2030 in other countries.

For the best available technologies, the information is taken from various sources that are indicated in the different sections.

3.1. Residential Sector

Lighting

Our analysis considered LEDs as the best available technology for residential lighting. Typical LEDs are designed to operate at low currents to provide efficient, low-level illumination. They are therefore ideal for applications such as small flashlights and headlamps. White LEDs for general-purpose lighting are more problematic, however, because LED's –luminous efficacy, expressed in lumens per watt (lm/W), typically drops dramatically at high currents and temperatures. Powerful LEDs require extensive heat sinks to provide optimum illumination. In additional, the most efficient LEDs emit in blue wavelengths, which are unsuitable for general-purpose lighting. To achieve acceptable general illumination, LED lamps require the use of phosphors to convert the blue light to a white spectrum similar to that of incandescent or fluorescent bulbs. These phosphors diminish the total efficiency of the LED. These factors along with cost have prevented widespread use of LEDs for general lighting applications.

Standard incandescent lamps operate at roughly 15 lm/W efficacy. Good-quality compact fluorescent light bulbs (CFLs) can achieve 60 lm/W, especially when replacing 60W or 100W incandescent light bulbs. Although white LEDs can achieve greater -efficacies under controlled testing conditions, in practice current LED bulbs are generally no better than CFLs at approximately 60 lm/W. This is primarily because of heat dissipation problems and phosphor losses. Ideal field conditions using top-of-the-line commercial white LEDs could reasonably achieve 100 lm/W[3]. The most advanced, state-of-the-art, white LEDs currently exceed 250 lm/W[4] in controlled laboratory conditions but commercialization is likely several years away.

The website 1000bulbs.com in early 2012 showed that a few LED models with a luminosity output equivalent to that of a 60W incandescent bulb achieve a rated efficiency of 100 lm/W or higher (Gerke, 2012). For our analysis, we assume that large-scale commercialization of 100-lm/W LED general-purpose light bulbs is achievable, at a reasonable cost for consumers. Table 2 shows our lighting assumptions.

[3] See also DOE's L-Prize: http://www.lightingprize.org
[4] http://www.cree.com/news-and-events/cree-news/press-releases/2012/april/120412-254-lumen-per-watt

Table 2. Lighting Assumptions

Lighting type	BAU (Lm/W)	BAT (Lm/W)	Technology Description	Reference
Incandescent	15	100	LEDs	1000bulbs.com*
CFL	60			

*Last accessed 02/09/2012

Televisions

The majority of televisions (TVs) sold today use either liquid crystal display (LCD) or plasma display. With over 90% of the sales, LCD TVs dominate the TV market (Park et al., 2012). LCD TVs operate by adjusting the transmissivity of the LCD panel to let through varying amounts of light generated by a backlight in the TV. Only a small fraction of the light generated by the backlight ever reaches the viewer, however, because of the cumulative light losses from all the layers in an LCD TV (e.g., , color filters, diffusion films, polarizers).

Large efficiency gains are possible if the most efficient optical components (e.g., reflecting films, high-transmissivity diffusing films, low-loss liquid crystals) are used in addition to more efficient backlight sources (LEDs instead of fluorescent lamps). Automatic brightness control sensors can also save energy by reducing TV brightness in low ambient light conditions.

Efficiency gains are also possible from adoption of organic LED technology (OLED). OLEDs are similar to standard semi-conductor LEDs but use a plastic polymer rather than a semi-conductor as the substrate. These plastics can be deposited in very thin, flexible films and manufactured in very small sizes (i.e., the size of a pixel on a television. OLEDs are small enough to eliminate backlighting entirely; the OLEDs themselves serve as light-producing pixels. This eliminates most of the optical stack in a typical LCD TV and all the associated light losses. The end result is a display panel that is remarkably thin compared to existing other screen technologies current models and is also flexible and consumes far less power than any current technology. Current applications are generally limited to small sizes (e.g., cell phone and personal digital assistant [PDA] screens) although small-size OLED TVs were already commercially available. Some manufacturers have already announced the coming availability of OLED TVs of 55” screen. However, some concerns persist regarding the lifetimes and color rendition of these prototypes as well as prohibitive production costs. Despite these concerns, we assume that, given the extremely rapid pace of technological innovation in consumer electronics, by 2015, OLED TVs in all sizes will be commercialized, and large-scale production will be possible at reasonable cost. Table 3 shows our television assumptions.

Table 3. Television Assumptions

Television type	BAU (EEI*)	BAT (EEI)	Technology Description	Reference
CRT	0.66	0.15	OLEDs	Park et al., 2011
LCD	0.20-0.31			
Plasma	0.31			

*The Energy Efficiency Index (EEI) is a metric used in European labeling to express the efficiency of an appliance as the ratio between the on-mode power and the maximum power for an appliance of the same size (EC 2010)

Refrigerators-Freezers

There are many options for improving the efficiency of standard top-mount refrigerator, including: enlarging the heat exchange area, improving compressor efficiency (using improved materials to reduce motor losses), and incorporating the following: variable-speed compressors to adjust output based on external conditions (low-level continuous operation is generally more efficient than start-stop operation), VIPs, adaptive defrost and anti-sweat heaters, top-mounted condensing coils, direct-current (DC) fan motors, smaller-sized and separate compressors for fresh food and freezer storage, and improved gasket seals. These options are available on current models, but no single refrigerator currently utilizes all of these design options. U.S. DOE's analysis found that a maximum technology design incorporating all of these features would yield up to a 36-percent increase in overall efficiency compared to the current standard (U.S. DOE 2011). In the EU labeling program, A+++ refrigerators have an energy-efficiency index (EEI) of 22 or less (EC 2010a), which is 50-percent more efficient than the current refrigerator minimum EEI of 44 as set by the Ecodesign MEPS taking effect in 2012 (EC 2008). Because of the differences in sizes, refrigerator configurations, and test procedures, there is no single UEC or efficiency target for refrigerators. For the same technology combination, each region has a different UEC based on the available local reference or a regional proxy. If neither of these local information sources is available, we assume that a 50-percent reduction in energy consumption is achievable based on information for the U.S. and the EU. Table 4 shows our refrigerator-freezer assumptions.

Table 4. Refrigerator-Freezer Assumptions

Country	BAU (kWh*)	BAT (kWh)	Technology Description / Existing Target	Reference
United States + Canada	580	440	Engineered based on most efficient components available on the market:	U.S. DOE, 2011a
Mexico	370	120	A+++ (assuming similar sizes and configuration as the EU across all countries)	EC, 2010a
European Union	280	120		
Russia	540	120		
South Africa	540	120		
Brazil	360	120		
India + Indonesia	470	240	50% Improvement	LBNL assumption
China	400	200		
Australia	700	350		
Japan	520	260		
Korea	690	340		

* kilowatt hour

Freezers

The available technological improvements for freezers are much the same as for refrigerators, including a larger heat exchange area, improved compressor efficiency (using improved materials to reduce motor losses), and incorporating the following: variable-speed compressors to adjust output based on external conditions (low-level continuous operation is generally more efficient than start-stop operation), VIPs, adaptive defrost and anti-sweat heaters, DC fan motors, and improved gasket seals. Table 5 shows our freezer assumptions.

Table 5. Freezer Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description/ Existing Target	Reference
United States	390	240	Engineered	U.S. DOE, 2011a
European Union	260	130	A+++	EC, 2010a

Water Heaters

Standard electric resistance storage water heaters have an energy factor (EF) of 0.9 whereas standard gas water heaters have an EF of about 0.6 (0.67 in the U.S. with the adoption of amended standards). The most efficient models available on the market today are heat-pump water heaters for electric heating (2.35 EF) and condensing water heaters for gas heating (0.9 EF) (U.S. DOE 2010). Although some technologies exist to improve the efficiency even further, such as electric CO_2 heat-pump water heaters (3.0 EF, using CO_2 as a refrigerant) and gas-fired absorption heat pump water heaters (approximately 1.4 EF), we consider these technologies to be too difficult to deploy globally on a large scale. The maximum technology targets above are used for temperate-climate countries like the U.S., Canada, and the EU. For warmer countries, we consider solar water heaters to be the BAT. Our calculation assumes that solar water heaters reduce energy consumption by 70 percent. Tables 6 to 8 present the resulting UECs.

Instantaneous gas-fired water heaters are not considered as an alternative to storage tank water heaters in our analysis. Although instantaneous water heaters eliminate standby losses, their burners are far less efficient than burners in standard gas-fired storage water heaters. Therefore, instantaneous water heaters can perform less efficiently for certain households, such as those with high hot-water demand (multiple inhabitants), simultaneous hot-water end uses, and hot-water end uses located far apart. Tables 6, 7, and 8 show our assumptions for electric storage, gas storage, and instantaneous water heaters, respectively.

Table 6. Electric Storage Water Heater Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
United States + Canada	2,500	1,200	Heat Pump EER* 2.35	U.S. DOE, 2010a
European Union	2,200	830		
China	620	190	Solar Water Heater	LBNL assumption
Australia	3,600	1,100		
South Africa	1,100	330		

* EER – energy-efficiency ratio

Table 7. Gas Storage Water Heater Assumptions

Country	BAU (GJ*)	BAT (GJ)	Technology Description	Reference
United States + Canada	16.8	12.6	Condensing EF 0.9	U.S. DOE, 2010a
European Union	11.9	9.1		
China	5.1	1.5	Solar Water Heater	LBNL assumption
Mexico	20.9	6.3		
Australia	15.4	4.6		

*GJ - gigajoule

Table 8. Instantaneous Water Heater Assumptions

Country	BAU (GJ)	BAT (GJ)	Technology Description	Reference
United States	11	9.6	Condensing EF 0.95	U.S. DOE, 2010a
European Union	9	7.4		
Australia	11	3.4	Solar Water Heater	LBNL assumption

Room Air Conditioners

The more efficient designs in the EC Ecodesign preparatory study for air conditioners (EC 2009) utilize efficient compressors, improved heat exchangers, improved fan blade design and motor efficiency, and improved expansion valves. Variable-speed compressors allow for more continuous low-level cooling, eliminating inefficient compressor cycling. The variable-speed capability allows the air conditioner to adjust its output smoothly according to ambient conditions and improves evaporator coil performance.

Engineered window room air conditioners can have energy-efficiency ratio (EER) of 4.4. Very few window-type room air conditioners are sold in China, so they are not covered here (Baillargeon et al. 2011).

For split systems, we consider reversible units as well as cooling-only units (Shah, Waide, and Phadke 2012). Because cooling and heating modes have different efficiencies, the resulting BAT targets vary by country depending on cooling and heating loads. Split systems in the U.S. are treated under the central air conditioner end use because of their relatively large size and heavy use compared to conditions in the rest of the world (Baillargeon et al. 2011). See Tables 9 and 10 for a summary of our assumptions regarding window and split air conditioners.

Table 9. Window Air Conditioner Assumptions

Country	BAU (EER)	BAT (EER)	Technology Description	Reference
United States +Canada	2.9	4.4	Engineered based on the best components available the market	EC, 2009a
Mexico	3.0			
European Union	3.2			
India	2.6			

Table 10. Split Air Conditioner Assumptions

Country	BAU (SEER*)	BAT (SEER)	Technology Description	Reference
Australia	2.9	8.6	Engineered based on the best components available the market	Shah et al., 2012
Brazil	2.9	8.8		
Canada	4.6	8.3		
China	4.1	7.3		
European Union	4.1	8.3		
India+Indonesia	3.6	7.9		
Japan	5.2	7.9		
Korea	4.8	8.5		
Mexico	3.7	9.7		
Russia	3.6	10.2		
South Africa	3.6	7.9		

* seasonal energy-efficiency ratio

Central Air Conditioners and Heat Pumps

The technologies used to improve the efficiency of central air conditioners and heat pumps are much the same as for other air conditioners (e.g., window units). Using improved heat exchangers and variable-speed compressors with brushless DC permanent-magnet motors are the main ways to improve central air conditioning and heat-pump systems. In addition, to maximize the efficiency of the whole-house system, a variable-speed air handler/furnace fan is necessary. Installing a system with all of these efficient components can reduce energy use by nearly 50 percent compared to systems without these components. The most efficient central systems on the market today achieve a seasonal energy efficiency ratio (SEER) of more than 24 (but require both the compressor and air handler to be optimized) (U.S. DOE 2011). We consider this maximum technology level to be achievable on a large scale by 2015. Table 11 shows our central air conditioner and heat pump assumptions.

Table 11. Central Air Conditioner and Heat Pump Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
United States + Mexico	3,100	2,400	Target is a mix of all product classes with SEER ranging between 16.5 and 24.5.	U.S. DOE, 2011c
Canada	1,700	1,300		
Australia	430	340		

Furnaces

Typical residential furnaces have an annual fuel utilization efficiency (AFUE) of 80 percent. The most efficient units currently available on the market are condensing furnaces with AFUEs of 98 percent or higher. The condensing burner captures much of the combustion heat in the waste flue gas stream and causes the water vapor to condense. As a result, condensing furnaces must be connected to a drain or a removable container that collects the condensate. In addition to having a condensing burner, the most efficient furnaces are coupled with efficient furnace fans capable of variable-speed operation (U.S. DOE 2011). Table 12 presents our furnace assumptions.

Table 12. Furnace Assumptions

Country	BAU (GJ)	BAT (GJ)	Technology Description	Reference
United States	36	29	Condensing unit	U.S. DOE, 2011 c
Canada	79	64		

Boilers

As is the case for gas water heaters and furnaces, the maximum-efficiency technology for both gas- and oil-fired boilers is a condensing unit. Condensing boilers operate at a lower system temperature than other boilers, which improves overall efficiency and results in condensation of flue gases. This captures much of the latent flue-gas heat that would otherwise escape out the boiler chimney. As with condensing units for other products, the condensate is acidic and must be drained away. Tables 13 and 14 show our assumptions for gas and oil boilers, respectively.

Table 13. Gas Boiler Assumptions

Country	Base Case (GJ)	BAT (GJ)	Technology Description	Reference
United States	80	64	Condensing unit EF 99%	U.S. DOE, 2008
Canada	74	60		
European Union	44	36		
China	10	9		

Table 14. Oil Boiler Assumptions

Country	Base Case (GJ)	BAT (GJ)	Technology Description	Reference
United States	83	70	Condensing EF 95%	U.S. DOE, 2008
European Union	44	37		

Fans

Typical ceiling fans use either standard shaded-pole motors or split-capacitor motors. These motors have substantial inductive losses but are generally very inexpensive. Replacing these motors with a brushless DC motor can improve the efficiency of a ceiling fan by 50 percent (Sathaye et al. 2012). In addition, fan blades can be designed with an airfoil-like shape that circulates air more smoothly than traditional designs. This reduces the turbulent flow surrounding the blade, reduces air friction losses, and circulates air more freely with less power than is the case in conventional fans. Sathaye (2012) found that efficient blade design can improve the efficiency by 13 percent. The combination of both efficient features (a brushless DC motor and improved blade design), which is used in most efficient ceiling fans currently on the market, improves efficiency by 54 percent compared to fans without these components. Table 15 shows our fan assumptions.

Table 15. Fan Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
United States	78	36	Engineered based on best components available on the market:	Sathaye et al., 2012
European Union + Canada + Russia	11	5		
Mexico + South Africa + Brazil	88	41		
India + Indonesia	150	69		
China	100	47		
Japan + Korea + Australia	21	10		

Standby Power

A recent study (EC, 2007) examined standby power consumption of a variety of home appliances, consumer electronics, and lighting. The study analyzed BAT for a variety of standby modes, including losses from power supplies, maintaining some secondary functionality, and network-related functionality. For the majority of equipment and standby modes considered, the BAT for standby power was significantly less than 1 W. The benchmarking study identified models with a hard-off switch with off mode between 0 and 0,3W and a reactivation mode of 0.1W. We therefore consider 0.1 W to be feasible and achievable in the very near future for most appliances and equipment. See Table 16 for a summary of our standby power assumptions.

Table 16. Standby Power Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
All	18	0.7	0.1W Standby	EC, 2007

Clothes Dryers

The most efficient electric clothes dryer technology is the heat pump. Instead of directly heating air via an electric or gas burner, a heat-pump clothes dryer uses a vapor-compression loop to transfer heat to the dryer. Although this generally requires a longer drying cycle than conventional dryers, heat-pump clothes dryers can also operate in a closed loop without the need for venting (a desirable trait in space-constrained apartments, for example). Compared to standard electric clothes dryers, heat-pump clothes dryers can reduce energy consumption by approximately 40 percent. Currently no heat-pump clothes dryers are widely available in the U.S. although they have an increasing market share in Europe (Werle et al. 2011). See Table 17 for a summary of our assumptions regarding clothes dryers.

Table 17. Clothes Dryer Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
United States	390	240	Heat Pump	U.S. DOE, 2011b
European Union	540	350		EC, 2009b

3.2. Industrial Sector

Motors

We used the MotorMaster database (U.S. DOE, 2010b) to determine the best available motors sold in the U.S. for each representative capacity in the product classes analyzed in BUENAS. The most efficient U.S. models were assumed to be the international BAT. The most efficient motor is a brushless DC permanent-magnet motor with an efficient core (e.g., laminated amorphous metal), low-resistance conductors, and low-friction bearings. DC motors allow for easy adaptation to variable-speed applications, which can save a large amount of system energy (e.g., as part of a pumping system, but we include only the motor efficiency here, not system savings). We note that, in percentage terms, motor losses tend to decrease with increasing motor power. Table 18 shows our assumptions for motors.

Table 18. Motor Assumptions

Motor type	BAU (Eff%)	BAT (Eff %)	Existing Targets	Reference
0.75-7.5 kilowatts (kW) (1.1 kW)	74%-84%	89%	Targets identified in MotorMaster database for representative models	U.S. DOE, 2010b
7.5-75 kW (11 kW)	87%-91%	94%		
> 75 kW (110 kW)	93%-95%	96%		

Distribution Transformers

Distribution transformer efficiency can be improved through the use of an amorphous metal core and hexaformer geometries. The atypical geometry used by hexaformer distribution transformers can reduce transformer losses by as much as 30 percent compared to conventional transformers. In addition, transformers can be coupled with intelligent control systems so that a single transformer is replaced by three smaller transformers with a centralized control. This allows the transformer system to only use a single smaller transformer when system loads or low and to use all three transformers when system loads are high. Each individual transformer is used closer to its highest rated capacity more of the time (or not energized if not needed), which improves overall efficiency. Hexaformer transformers using this control scheme can reduce energy losses by approximately 50 percent. Table 19 shows our assumptions for distribution transformers.

Table 19. Distribution Transformer Assumptions

Country	BAU (kWh)	BAT (kWh)	Technology Description	Reference
United States + Canada	2,600	1,000	Engineered: amorphous metal core, hexaformer geometries and controls	U.S. DOE, 2012 and EC, 2010b
European Union	19,000	7,400		
India	2,700	1,100		
China	11,000	3,100		

Note: For India and China, we analyze only liquid-type distribution transformers. For the U.S. and Canada, all product classes covered by U.S. DOE are considered in weighted average.

4. Method of Calculating Potential Savings

BUENAS uses the sales forecast as described in McNeil et al. (2011) as an input to calculate the energy consumption of the appliance stock in a given country according to base-case (market-driven) efficiency improvements, changes in the market share of efficiencies as a result of MEPS, and equipment turnover.

We calculate national energy savings (NES) in each year by comparing the national energy consumption, *E*, of the end use under study in the BAU to the BAT case, as follows:

$$NES(y) = E_{BAU}(y) - E_{BAT}(y)$$

BUENAS calculates final energy demand according to the UEC of equipment sold in previous years:

$$E = \sum_{age} Sales(y - age) \times UEC\ (y - age) \times Surv(age)$$

Where:

- *Sales (y)* = unit sales (shipments) in year *y*
- *UEC(y)* = unit energy consumption of units sold in year *y*
- *Surv(age)*= probability of surviving to *age* years

The following equations are implemented in the Long-range Energy Alternatives Planning (LEAP) system[5] (Heaps 2012) to calculate emissions mitigation potentials.

We calculate total reduction in CO_2 emissions in million tons (Mt) using a typical electricity generation fuel mix and fuel combustion factor.

CO_2 emissions savings are calculated from energy savings by applying a carbon factor to site energy savings, as follows:

[5] LEAP is an integrated modeling tool developed at the Stockholm Environment Institute that can be used to track energy consumption in all sectors of an economy for energy policy analysis and climate change mitigation assessment.

$$\Delta CO2(y) = \Delta E(y) \times f_c(y)$$

Where:

- $\Delta CO_2(y)$ = CO_2 emissions mitigation in year y
- $\Delta E(y)$ = final energy savings in year y
- f_c = carbon conversion factor (kilograms per kilowatt hour [kg/kWh]or kg per gigajoule [kg/GJ]) in year y

5. Results: Potential Savings

Tables 20 and 21 present the estimated energy savings from the BAT MEPS in 2020 and 2030, by country and end use, based on the calculation method and the assumptions described above. To simplify the reading of the results, we convert fuel savings into terawatt hours (TWh).

Table 20. Site Energy Savings from BAT Standard in 2020 (TWh)

End Use / Country	AUS	BRA	CAN	CHN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Boilers			2.7	29	100								10	140
Central Air Conditioners	0.04		0.7							0.1			28	29
Dryers					6								10	16
Fans	0.12	3.2	0.1	26	1	22	2.5	0.5	0.2	0.9	0.3	0.4	8	65
Freezers					5								2	7
Furnaces			12.0										36	48
Lighting	2.05	26.0	6.3	45	29	19	8.8	0.6	0.2	9.5	24.8	4.1	29	200
Refrigerators	2.17	10.6	1.5	51	11	6	6.6	6.8	2.5	2.5	6.2	2.3	14	120
Room ACs[**]	0.15	14.4	0.1	10		42	4.1		0.7	4.3			8	84
Heat Pumps	2.97		0.3	55	14			28.0	1.0	0.6	3.9			110
Televisions	1.32	2.2	1.6	11	11	3	0.8	1.6	2.0	1.2	1.9	0.3	14	51
Washing Machines				23	2				0.2					25
Stand by	1.11	5.3		36	42	16	3.2	5.3		2.4	4.1	0.8	31	150
Water Heaters	13.70		5.3	80	120					45.0		2.1	76	340
Residential	23.63	61.8	30.9	370	340	110	26.0	42.8	6.8	66.4	41.1	10.0	270	1,400
Transformers			0.3	16	15	4							9	44
Electric Motors	0.90	3.3	1.3	53	20	10	4.2	7.5	5.8	1.2	7.3	1.1	11	130
Industry	0.90	3.3	1.6	69	35	14	4.2	7.5	5.8	1.2	7.3	1.1	20	170
Total	24.53	65.1	32.6	430	370	120	30.2	50.3	12.6	67.6	48.4	11.0	290	1,600

[**]The commercial sector from the original study (Shah et al. 2012).

Table 21. Site Energy Savings from BAT Standard in 2030 (TWh)

End Use / Country	AUS	BRA	CAN	CHN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Boilers			7.0	89	250								26	370
Central Air Conditioners	0.1		1.6							0.2			70	71
Dryers					14								26	41
Fans	0.2	6.6	0.2	51	2	45	5.2	0.9	0.5	1.7	0.6	0.7	16	130
Freezers					12								5	17
Furnaces			34.0										91	120
Lighting	2.1	9.5	2.8	22	9	8	3.1	0.7	0.3	3.4	9.7	1.4	32	100
Refrigerators	5.5	28.0	3.7	120	23	18	21.0	16.0	6.0	6.3	14.0	5.7	35	300
Room ACs	0.4	41.0	0.2	22		130	12.0		1.6	13.0			13	240
Heat Pumps	7.1		1.0	120	36			62.0	2.1	2.2	10.0	0.1		240
Televisions	2.0	5.0	3.1	21	23	7	1.8	2.9	4.1	2.5	3.8	0.6	27	100
Washing Machines				46	4				0.5					51
Stand by	1.9	9.9		78	70	33	5.6	7.9		4.2	7.0	1.4	56	270
Water Heaters	29.9		11.5	150	290					130.0		5.6	150	780
Residential	49.2	100.3	65.1	720	730	250	48.2	89.6	15.2	161.3	45.6	15.4	550	2,800
Transformers			0.9	44	48	13							26	130
Electric Motors	2.3	9.5	3.3	120	45	32	12.0	17.0	16.0	3.4	19.0	3.0	28	310
Industry	2.3	9.5	4.2	170	93	46	12.0	17.0	16.0	3.4	19.0	3.0	54	440
Total	51.5	109.8	69.3	880	830	290	60.1	106.8	31.6	164.7	64.9	18.0	600	3,300

Among the key results are:

- By 2030, 80 percent of the energy savings potential is concentrated in the EU, China, the U.S., and India.

- Introducing heat-pump and solar water heaters in countries that consume significant amounts of hot water, such as the EU, China, the U.S. and Mexico, produces the largest savings of all the end uses: 780 TWh. The baseline energy consumption for hot water heating is typically high because hot water is commonly used in countries with temperate climates. In addition, the increase in efficiency between traditional storage tank water heaters and heat-pump or solar water heaters is significant. India is not included in the hot water heater analysis because of lack of data, but savings from implementing high-efficiency hot water heaters in that country are expected to be substantial as well.

- Air conditioning has the second-greatest potential for energy savings, at 480 TWh for room air conditioners and 70 TWh for central air conditioners. This is a result of the high per-unit savings potential combined with an increased penetration of air conditioning devices and increased cooling loads in the developing world as well as the increasing use of heat pumps in temperate climates.

- Motors have the third-largest potential to save energy, with 39 percent of the savings potential in China.

Tables 22 and 23 present the annual CO_2 emissions reduction from BAT MEPS, per end use and country in 2020 and 2030.

Table 22. CO_2 Emissions Reduction from BAT Standard in 2020 (Mt CO_2)

End Use / Country	AUS	BRA	CAN	CHN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Boilers			0.4	6	39								4	49
Central Air Conditioners	0.03		0.1							0.04			17	17
Dryers					2								6	8
Fans	0.10	0.3		27	0	19	1.7	0.2	0.1	0.58	0.1	0.3	5	54
Freezers					2								1	3
Furnaces			2.4										7	10
Lighting	1.66	2.3	1.3	46	10	17	6.1	0.3	0.1	6.21	7.4	3.0	17	120
Refrigerators	1.76	0.9	0.3	52	4	5	4.5	2.7	1.0	1.64	1.8	1.7	8	86
Room Air Conditioners	0.12	1.3		11		38	2.8		0.3	2.81			5	61
Heat Pumps	2.40		0.1	56	5			11.0	0.4	0.41	1.2			76
Televisions	1.07	0.2	0.3	11	4	2	0.5	0.6	0.8	0.77	0.6	0.2	8	30
Washing Machines				24	1				0.1					24
Stand by	0.90	0.5		37	15	15	2.2	2.1		1.56	1.2	0.6	18	94
Water Heaters	7.70		1.1	31	35					9.00		1.6	30	120
Residential	15.73	5.4	6.0	300	120	97	18.0	17.1	2.9	23.04	12.3	7.5	120	750
Distribution Transformers			0.1	16	5	4							6	31
Electric Motors	0.73	0.3	0.3	54	7	9	2.9	3.0	2.4	0.79	2.2	0.8	6	90
Industry	0.73	0.3	0.3	70	12	13	2.9	3.0	2.4	0.79	2.2	0.8	12	120
Total	16.46	5.7	6.3	370	130	110	20.9	20.1	5.3	23.83	14.4	8.3	140	870

Table 23. CO_2 Emissions Reduction from BAT Standard in 2030 (Mt CO_2)

End Use / Country	AUS	BRA	CAN	CHN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Boilers			1.1	18	95								10	120
Central Air Conditioners	0.1		0.3							0.1			40	40
Dryers					5								14	19
Fans	0.2	0.6		49	1	38	3.4	0.3	0.2	1.1	0.2	0.5	9	100
Freezers					4								3	7
Furnaces			6.6										18	25
Lighting	1.6	0.8	0.6	21	3	7	2.0	0.2	0.1	2.2	2.7	0.9	18	60
Refrigerators	4.1	2.4	0.7	110	8	15	13.9	5.8	2.3	4.1	4.0	3.8	20	200
Room ACs	0.3	3.5		21		110	7.7		0.6	8.2			8	160
Heat Pumps	5.4		0.2	110	12			22.9	0.8	1.4	2.8	0.1		160
Televisions	1.5	0.4	0.6	20	8	6	1.2	1.1	1.6	1.6	1.0	0.4	15	58
Washing Machines				45	1				0.2					46
Stand by	1.5	0.8		74	24	28	3.7	3.0		2.7	1.9	0.9	32	170
Water Heaters	15.8		2.3	56	83					25.7		3.7	61	250
Residential	30.3	8.6	12.5	530	240	210	32.0	33.3	5.9	47.1	12.6	10.0	250	1,400
Distribution Transformers			0.2	42	16	11							15	84
Electric Motors	1.7	0.8	0.7	120	15	28	7.9	6.4	6.4	2.2	5.3	2.0	16	210
Industry	1.7	0.8	0.8	160	31	39	7.9	6.4	6.4	2.2	5.3	2.0	31	290
Total	32.0	9.4	13.3	690	270	250	39.9	39.7	12.3	49.2	18.0	12.0	280	1,700

When we consider carbon emissions reductions (Tables 22 and 23) on top of energy savings (Tables 20 and 21), savings are distributed a bit differently than is the case for energy savings alone, with more emphasis on countries whose power generation systems are heavily carbon based, such as China and India, and less emphasis on fuel savings in countries like the EU. Most of the emissions mitigation potential is concentrated in China, the U.S., India, and the EU. In 2030, nearly 90 percent of total emissions reduction potential in these countries.

Table 24. Cumulative CO_2 Emissions Reductions from BAT Standard through 2030 (Mt CO_2)

End Use / Country	AUS	BRA	CAN	CHN	EU	IND	IDN	JAP	KOR	MEX	RUS	ZAF	USA	Total
Boilers			9	140	850								82	1,090
Central Air Cond.	1		3							1			360	363
Dryers					45								130	178
Fans	2	6	0	520	7	390	35	4	2	11	2	5	92	1,070
Freezers					38								23	61
Furnaces			56										160	216
Lighting	24	30	17	610	130	230	80	4	2	82	98	39	370	1,710
Refrigerators	38	21	7	1,100	79	130	110	56	22	36	38	36	180	1,840
Room ACs	3	30	0	210		940	66		6	68			88	1,410
Heat Pumps	51		2	1,100	110			230	8	11	26	1		1,560
Televisions	19	4	6	210	79	52	11	12	17	16	11.0	4	160	601
Washing Machines.				460	13				2					478
Stand by	16	9		730	270	280	41	36		29	22	11	340	1,790
Water Heaters	160		22	600	760					210		34	620	2,400
Residential	310	99	120	5,700	2,400	2,000	340	340	58	470	200	130	2,600	14,800
Transformers			2	360	130	87							130	704
Electric Motors	16	7	6	1,100	150	230	68	62	55	19	48	18	140	1,940
Industry	16	7	7	1,500	270	310	68	62	55	19	48	18	270	2,650
Total	330	110	130	7,200	2,700	2,300	410	400	110	490	240	150	2,900	17,400

Annual and cumulative emissions reductions are roughly proportional, except for end uses for which we consider a moving baseline such as lighting. The savings potential for lighting is estimated at 1.7 Gt of CO_2 through 2030. The overall cumulative savings are 17.4 Gt of CO_2 through 2030.

6. Results Summary and Conclusions

Table 25 summarizes the savings from the standards studied, for every country covered in BUENAS.

Table 25 . Global Results for All Countries in 2020 and 2030 under the BAT Scenario

	Annual Savings in 2020				**Annual Savings in 2030**				**Cumu-lative**
	Elec	Gas	% red vs. BAU	CO_2	Elec	Gas	% red vs. BAU	CO_2	CO_2
End Use	TWh	PJ	%	Mt	TWh	PJ	%	Mt	Gt*
Air Conditioning	220		20%	150	550		37%	360	3.3
Fans	65		32%	54	130		54%	100	1.1
Lighting	200		42%	120	100		22%	60	1.7
Refrigerators & Freezers	130		21%	88	320		44%	200	1.9
Space Heating	0	690	6%	59	0	1,800	14%	150	1.3
Standby	150		65%	94	270		90%	170	1.8
Television	51		28%	30	100		45%	58	0.6
Laundry	40		15%	24	90		28%	65	0.7
Water Heating	140	740	18%	120	320	1,700	37%	250	2.4
Total Residential	**1,000**	**1,400**	**16%**	**740**	**1,900**	**3,500**	**27%**	**1,400**	**14.8**
Dist Transformers	44		11%	31	130		27%	84	0.7
Motors	130		2%	90	310		5%	210	1.9
Total Industry	**170**		**3%**	**120**	**440**		**6%**	**290**	**2.6**
Total	**1,200**	**1,400**	**10%**	**860**	**2,300**	**3,500**	**19%**	**1,700**	**17.4**

* Gt - gigatons

In sum, the impacts of adopting MEPS requiring BAT are:

- 1,200 TWh of electricity savings in 2020 and 2,300 TWh in 2030
- 1,400 petajoules (PJ) of fuel savings in 2020, and 3,500 PJ in 2030
- 27-percent energy reduction among residential end uses and 6 percent among industrial end uses in 2030
- 860 Mt of annual CO_2 emissions reductions by 2020 and 1,700 Mt by 2030.
- 17 gigatons (Gt) cumulative emissions reduction between 2015 and 2030.
- Highest potential final energy savings (electricity and fuel combined) for water heating; highest potential CO_2 savings for air conditioning.

This study shows that, through implementation of aggressive policies targeting technically achievable efficiencies, final energy consumption can be reduced by 19 percent in 2030 in the residential and industrial sectors compared to a business-as-usual scenario. As a result, worldwide annual CO_2 emissions would be reduced by 860 Mt in 2020 and 1.7 Gt in 2030. As a comparison, recently implemented or in-progress standards from SEAD partner countries will save an estimated 220 Mt of CO_2 (McNeil et al. 2012). The Cost-effective Potential scenario defined in Letschert et al. (2012), which includes a set of cost-effective targets covering roughly the same scope as the BAT scenario, identifies 1,100 Mt of CO_2 mitigations by 2030. Thus, one can conclude that current cost-effective efficiency targets, even if applied worldwide, would only capture about two-thirds of the potential offered by state-of-the-art technologies.

To put these results into context, we compare them to the reductions that the International Energy Agency determined would be necessary to stabilize global CO_2 concentration at 450 ppm. (IEA 2010) Emissions mitigation from the BAT scenario achieves approximately 11 percent of the total emissions reduction target of 15 Gt[6], which includes energy demand reductions in buildings, industry, and transport as well as increases in the share of renewable energy. If we look at reduction in electricity demand in buildings only, we find that the BAT would achieve 80 percent of the savings target. In the industrial sector, the savings from BAT MEPS would achieve 25 percent of the IEA 450-ppm scenario savings target. In fact, implementation of BAT for electricity end uses in only the residential and industrial sectors would produce 60 percent of total final electricity demand reductions that are needed.

The main "take-away" message from BAT scenario analysis is that wide adoption by 2015 of already marketable technologies in the buildings and industry sector could have a much greater impact than current policies. Furthermore, adoption of these technologies would contribute significantly to the effort to stabilize global CO_2 concentrations.

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